Investigation of the Potential for the Integration of AVIRIS and IFSAR for Urban Analysis

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Abstract

Understanding urban structures and processes is increasingly important as cities become the home of more of the earth's population. This paper describes the use of a study area in Los Angeles, California to test the potential for integrative use of Interferometric Synthetic Aperature Radar (IFSAR) and Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) hyperspectral imagery for analysis of an urban area. Interferometric radar is used to define the three dimensional (3-D) geometry of the surface features, topography, and impervious surfaces of the study area. Hyperspectral data is used in this paper to supplement the radar measurement and interpretation by assisting in the delineation of features and textural components of the study area. Integrative use of AVIRIS and IFSAR is a useful approach to delineate urban geometric structure at a meaningful level of spatial detail, while providing textural information upon this structure which is extensible to the regional level.

Introduction

The global tendency has been to locate cities in areas of sensitive environments, such as coastal zones, floodplains and prime agricultural lands. Thus, the changing structure, size and activity composition of cities has profound and disproportionate impacts on regional and global environmental change. With most of the earth's population living in cities, there exists a great need for a means of rapidly and accurately inventorying and monitoring urban areas. This is especially true in developing nations, where the urban information infrastructure necessary for urban planning and management is not in place (IGBP, 1995).

The urban landscape is extraordinarily complex. The urban landscape is the manifestation of both physical and human processes expressed in intricate geometries of land use and cover mixtures in relatively unpredictable spatial patterns. The current theories of urban structure are inadequate to explain, let alone predict urban patterns of land use and cover. Complicating the analysis of urban landscape is the cultural relativity of urban structure and process. Urban structure and pattern is markedly different in the cities of Latin America from those in North America or Asia.

Lacking a solid basis in theory to analyze urban areas around the world, better empirical tools must be developed to specify urban structure and process and their environmental impacts within given cultural contexts. Increased empirical analysis of these urban areas will yield better data, analysis and operational management options to decrease environmental impacts. Empirical analysis should yield insights suggesting future management policies and cross-cultural theoretical developments.

Numerous studies have been undertaken to use remote sensors for urban analysis (Haack, 1987; Khorram, 1987; Chavez, 1988; Wang, 1993). In general, the previous investigations have been plagued by these interrelated problems:

- limited analytical capabilities due to reliance on a single sensor,
- sensors not optimized for characteristics or complexity of the urban environment,
- spectral and spatial resolution of sensors are too coarse for detailed analysis of urban geometry,
- inability to discern detail of urban structure, while maintaining the extensibility for regional scale analysis,
- spatial patterns of land use/cover change have not been linked to the underlying urban processes that manifest themselves in the observed spatial patterns.

This paper will attempt to address some of these limitations using an integration of two sensors systems. Every urban area consists of a natural topography overlain by a human-created three dimensional topography of buildings, roadways, etc. The Interferometric Synthetic Aperture Radar (IFSAR) system is used to investigate an improved method for definition and measurement of the structural geometry of both the natural and human-created topographies in the urban area.

However, accurate geometric measurement of these features requires knowledge of the textural components of the urban landscape. In addition, the urban area is more than simply the structural geometry of discrete features. The linkages, composition and relative location of the mix of continuous natural and human phenomena expressed as land covers and land uses are essential to inventory and analysis of the urban area. Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data is examined as a means to provide the necessary spectral range for satisfying several of these purposes.

Previous Studies

While there has been an abundance of research in the use of remote sensing for monitoring urban areas, there are virtually no studies that have used AVIRIS for urban analysis (Gouinaud, 1996; Ridd, 1995; Weyhahl,1995; Gong,1992; Webber,1992; Haack,1987; Jensen, 1981). Several of these research efforts were limited by dependency on a single sensor unable to handle the complexity of the urban landscape. Recent research has pointed in the direction of the need for sensor data fusion using various available sensors and other data sources in order to increase the accuracy of land cover classification and the inference of human activity and land use. As an example, the Earth Observation Commercial Applications Program (EOCAP) sponsored a four year program to assess the performance of GIS based system for forecasting the needs of the BellSouth Telecommunications. This study fused the SPOT panchromatic and multispectral data with the NASA's Calibrated Airborne Multispectral Scanner (Jensen, 1994).

Among the available sensors used for urban analysis are the SPOT High Resolution Visible (HRV) multispectral data, SPOT panchromatic imagery, Landsat-TM, and aerial photographs, and Synthetic Aperture Radar(SAR). While the combination of the above data sources has produced some capabilities to inventory and map the urban system, the research to-date has a number of shortcomings such as urban classification accuracy, and availability of synchronous data (Webber, 1992). Census data and existing maps have provided additional important information for urban area mapping, however, these collateral data are often unavailable in cities of the developing world. Also the above sensors have not been able to measure critical features accurately, such as topography, structural dimensions, and the intra-urban vegetation.

The topography of urban areas which includes the 3-D geometrical patterns of human structures, in addition to the natural topography, is valuable in assessment of the land use in the urban setting. IFSAR data was used recently for land cover classification of a number of areas in the California and Oregon state (Rodriguez,1996). According to the studies sponsored by the European Commission - DG XIII- Application of Remote Sensing to Urban Areas, a spatial resolution of a meter is required for extraction of urban geometrical patterns (Casciati, 1997). Such a spatial resolution has not been available for monitoring of urban environment in the recent past, and has only been available recently by the operational SAR and IFSAR systems (Madsen, 1993; Soumekh, 1995). Additionally, an important attribute of IFSAR is its orthorectification properties, which eliminate foreshortening of terrain found in conventional SAR imagery. These properties aid in the coregistration of the radar imagery to other sensor data and maps.

Methodology

The methodology employed in this study is an integrative use IFSAR and AVIRIS imagery to enhance the information extraction potential beyond that which is available from either of the two sensors separately. The goals of the study are to:

1) use the AVIRIS data to assist in the delineation of urban features to allow more accurate measurement of both human and natural three dimensional geometry using the IFSAR sensor,

2) use of the AVIRIS data to provide textural information corresponding to the geometric information obtained by the IFSAR,

3) assess the potential and research requirements for future integrative use of the two sensors for urban analysis, inventory and monitoring.

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and Interferometric Synthetic Aperture Radar (IFSAR) provide crucial information which is not available in the previous studies. AVIRIS has a dynamic range of 224 channels, each 10 nm wide. This fineness of spectral resolution provides unparalleled ability to resolve absorption bands characteristic of the chemical composition of the earth's surface materials and vegetation(Goetz, 1985; Smith, 1990). Most analyses of multispectral sensor data, such as Landsat TM or SPOT, concentrate on the limited number of relatively wide bands for characterization of the earth's surface and features. The ability to resolve many more bands in hyperspectral data, such as

AVIRIS, extends this characterization capability beyond that of conventional multispectral data.

Two analytical approaches have been used in most AVIRIS applications. The classification of features and land cover is performed using statistical approaches for supervised and unsupervised classification and pattern recognition. The second approach employs the collection of a library of field spectra which are matched against spectral signals in the AVIRIS dataset. While the collection and comparison of field spectra for the urban landscape has several interesting possibilities, this research employs the first approach using statistical analysis of the image data to define land cover and features.

Analysis of the orthorectified IFSAR measures both the natural and human-created topography. In addition, the imagery contains the more conventional microwave reflectivity data for a scene. Interferometric processing uses either use multiple passes of the radar platform over a study area, or multiple measurements of the study area using two antennas on the same platform in a single pass. In this study, the measurement is performed using two antennas situated on the same radar platform, but are displaced perpendicular to its direction of the motion. The reflectivity response of the SAR image is composed of an intensity amplitude and a relative phase with respect to a reference. The intensity amplitude is a measure of the geometry of the illuminated area, the operating frequency of the SAR system, and the location of the illuminated area in terms of the radar position. The phase corresponds to the radar distance to the imaged area. Topography is generated by two SAR images with known displacement using their relative phase difference. The process of topography computation is automated and is currently operational (Madsen, 1993).

The IFSAR output products are produced on a rectangular grid in a coordinate system which is defined by -the direction of the platform motion, also know as the azimuth direction, and a perpendicular direction, known as the ground range. This coordinate system is transformable to any other geographical coordinate systems using a number of known ground control points. The resolution of the IFSAR measurement is dependent of the pulse bandwidth used for the range measurement, radar antenna length, the length of the synthesized aperture, and the amount of averaging which is performed in the processing algorithms for reducing various noise sources. For a more detailed account on the intrinsic resolution of SAR measurements, and effective resolution after processing, the reader should consult (Elachi, 1988). It must be pointed out the IFSAR operates at wavelengths which penetrate through clouds and fog, and is sensitive to the small scale geometry of the imaged scene.

The interaction of the radar signal with the urban environment is complicated due to the presence, and density of the human structures. As a result the interpretation of the derived IFSAR topography in the urban environment is different than those used for the natural terrain. The recent findings (Houshmand, 1996) for the interpretation of the IFSAR data over urban areas show that the detection of 3-D geometrical patterns are possible even in the presence of the complicating factors, such layover and radar signal bounce.

Study Area

The study area is in the Beverly Hills-Westwood sections of the Los Angeles region. The approximate area is shown in the AVIRIS image display in Figure 1. The study area is- representative of the diversity of urban land covers, uses and features in the region. While not a rapidly industrializing city in a developing nation, Los Angeles has many characteristics of urban structure and design in common with cities of Latin America, Africa and Asia. This is due to the historical evolution of Los Angeles from early Spanish settlement to a distinct orientation to Latin America in the modern time. Also the Mediterranean climate of Los Angeles fosters housing types, settlement patterns, and yearlong vegetative cultivation.

Corresponding coverages of the AVIRIS and IFSAR sensors for flights in 1994 were obtained. The AVIRIS data is taken from the Santa Monica Mountains flight of October 19, 1994. The data range for the 1994 imagery was from Band 1, bandcenter of 373.40 nm (.374 microns) to Band 224, bandcenter of 2503.26 nm (2.503 microns).

The IFSAR coverage of the study area is obtained on August 5, 1994. The IFSAR platform is on a NASA/JPL DC-8 aircraft which is flown at 11000 meter altitude for this measurement. The flight path for the radar platform is (33.97 Latitude, -118.47 Longitude) to (33.97, -1 18.41). The center of the imaged scene is (34.06, -1 18.44). The center frequency wavelength is .056689 meters and a transmit pulse length is 5 micro second with a” bandwidth of 40 MHz. The radar antenna separation is 2.5 meters. For this data acquisition, the IFSAR platform collected data over a 105 km path with a 12.8 km swath in one pass. The collected return signal for each antenna on the radar platform is 2.05 GBytes. The interferometric data is then processed using the JPL standard processor to produce a topography map of the imaged area, in addition to the orthorectified synthetic aperture radar intensity image. The data is reported on a regular grid of 5 meter posting with a vertical accuracy assessed at plus or minus 2.5 meters. The AVIRIS and IFSAR scenes were spatially subsetted to the match the study area boundaries.

Use of AVIRIS Imagery

The intent of the integration with the AVIRIS data is to assist in use of the IFS AR, not necessarily to develop a comprehensive land cover classification product for the study area. One of the initial problems encountered with the IFSAR measurement of the large buildings in urban areas is the effect of adjacent trees and smaller structures on the interferometric analysis. The intensity of the radar reflection of the adjacent tree canopies, walkways, and concrete areas can be as bright as the SAR image of buildings. The corresponding IFSAR measurement of building geometry is confounded by the heterogeneous signals around the buildings perimeter. In the analysis, the large trees and other features adjacent to building structures can effectively alter the building footprint in the IFSAR measurements. To address this problem, an analysis of AVIRIS data was employed to differentiate urban land covers and structural materials. To this end, a vertical perspective mask was derived to discriminate the vegetation and other materials adjacent to the buildings from the buildings to be measured.

A related problem very significant in the urban area involves the shadowing of features by other features. This problem is manifested in the imagery by mixed reflectance signals from a building or area being shadowed by another. Also one feature may actually block the active radar signal or impede or bounce the reflected signal from that blocked feature. This shadowing and the resultant signal distortion is a significant problem for the use of both AVIRIS and IFSAR in urban areas.

The initial analysis was to discover the combination of reflectance bands that could be used to identify and differentiate urban land covers and structural materials. Fieldwork and the use large scale aerial photography are used to define the regions of interest (ROI) or training sites for a supervised classification. Regions of interest (ROI) were taken from the imagery for each of four categories related to improving the IFSAR classification. These ROIS are grass, trees, roadway and large buildings. The histograms for each of these regions of interest are shown in Figure 2. The range of average reflectance values for 224 bands across all five categories was from zero to a maximum of approximately 6500.

The shape of the histograms for the buildings and roads are very similar. However, the magnitude of the reflectance values trended higher for buildings than values for roads. The range for Band 10 (bandcenter 460 nm) for roads 3553-5057, with a mean value of 4363.7. For buildings the range was 3781-6464 with a mean value of 5203.7.

Likewise, the histograms for trees and grass exhibit a similar shape across the 224 bands. They are approximately equal in value

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in the region of bands 5-15 (41 1.75- 509.3 rim). The average reflectance value for the grass ROI in band 10 was 3249. and the value for the tree ROI was 3021.5. In the region of the near infrared bands 42-50 (751.7- 828.3 rim), the values are markedly different. Grass has a mean value of 6491.1 in band 45 (780.4 rim). The mean value for trees is 4083.4 in band 45.

The potential to discriminate between the trees and grass adjacent to buildings and roadways and the those features is indicated in the histograms as well. The human-made urban features are quite distinctive across the respective histograms. Thus, the histogram analysis provided support for the hypothesis that the AVIRIS data could provide discrimination between urban features and land covers, particularly trees, relevant to the interpretation of the IFSAR imagery.

The massive dimensionality and size of the AVIRIS data set for even a relatively small urban study area makes coherent and consistent analysis and interpretation a challenge. Preliminary supervised and unsupervised land cover classifications did not yield useful results to address the specific problems involved in the interferometric measurement. Rather than attempt to classify the land covers surrounding the structures, the approach was undertaken to focus on delineation of the shapes (footprints) of the structures regardless of the surrounding land covers. In effect, to create a mask of all non-structures for use with the radar image.

Based on the results of the histogram analysis, a principal components analysis was undertaken to reduce the dimensionally of the data. The intent was to extract a single component that combined the information of the entire dataset to delineate the institutional and commercial buildings. The logic was to delineate the building shapes (footprints), from the surrounding roadways, trees and grass. The second principal component is portrayed in Figure 3. The individual housing units are-” indistinct, but the footprints of the larger structures on the UCLA campus and along Wilshire Blvd. are readily apparent.

Integration with IFSAR for Measurement

The topographic measurements produced by IFSAR contain the human structures, in addition to the natural terrain. The AVIRIS data provides a mask to delineate the footprints of these structures. The height of the structures are then derived from the measurements inside the building footprints.

Figure 4 shows the IFSAR topography map modulated with the radar intensity. . The dominant characteristics of the natural terrain are evident in this graphic. The spatial extent is 6.5 Km in the South-North direction, and 4.3 Km in the East-West direction. The elevation gain across the area is 170 meters from the South to the North, which is displayed as color variations from blue shade for the low elevation to brown for the high elevations. The radar intensity image indicates roads, city blocks, and urban boundaries in this image. The footprints of large buildings appear as brown pixels. Areas of black pixels indicate areas where IFSAR heights are not computed. These areas are located adjacent to large buildings where blockage and multiple reflections severely distort the radar signal.

In the complex urban environment, the vertical height dimension has many rapid changes in value. There is a necessity for a spatial resolution in the sensor data fine enough to capture these rapid changes, if precise 3-dimensional geometry is to be calculated. Large building structures appear as sharp topography discontinuities over the natural terrain. Since the IFSAR topography and radar intensity data is available on 5 meter posting, selected small areas can be quantitatively analyzed.

In order to determine the height of a building, the vertical heights of all the pixels inside the building footprint are used to form a histogram of the distribution. The peak of this histogram corresponds to a height value which was most frequently reported (mode) by the IFSAR measurement over the building footprint, and is designated as the height of the building. This histogram analysis is performed so that the pixels with erroneous height values (due to various noise sources such as multiple scattering from adjacent buildings, low signal level, and shadowing) will not bias the height estimate for the aggregate building. This procedure discards the height values for antenna towers which are frequently placed on the roof of large structures. This algorithm can underestimate the height of a building where the roof is not predominately flat. For example, this algorithm under estimated the height of the Pauley Pavilion building (in our study area) where the roof has a dome structure. For this type of structure, the building height is reported as the maximum measured height.

An oblique perspective of the study area in Figure 5. The scene is viewed from the North-West, where the look direction is toward the South-East. The buildings in the foreground are the the UCLA campus and the linear arrangement of taller buildings follows

Wilshire Boulevard. Figure 6 shows three selected building structures in the study area. The structure on the right side of the image is the federal building at the intersectionof 1-405 and Wilshire Blvd. It is 16 stories tall measured by the IFSAR analysis at 75 meters. On the left side the image is the Pauley Pavilion at UCLA measured at 17 meters. The actual height of Pauley Pavilion is 21 meters. The actual height is underestimated slightly, probably due to the shape of the building roof. The last structure is the Westside Pavilion (3 story shopping mall) at the south end of the study area which was measured at 15 meters.

Conclusions and Future Research

This study has undertaken a limited integration of IFSAR and AVIRIS for urban analysis. Our analysis confirms that the interferometric radar can be used to define the three dimensional (3-D) geometry of. the features and topography of the urban area. It is believed that additional features can be measured in the urban area, such as impervious surfaces and vegetation canopies. Using radar these measurements can be accomplished through clouds and urban air pollutants and across large regions in a cost effective manner.

Additional research is required to improve the accuracy and reliability of the IFSAR measurements in the urban area. Radar multi-path interference, adjacent structures and blockage effects continue to be significant problems. Computational and data acquisition approaches to minimize multiple reflection effects within the urban area are prime research areas. Assessing the effectiveness of increasing the ground resolution of the imaging sytem is currently under study. It is anticipated that research will yield the parameters necessary to tune the radar instrument specifically for urban analysis.

AVIRIS hyperspectral data is used in this paper to enhance the capability to measure with the IFSAR. There are other means to create the building footprint mask. However, AVIRIS is extensible to regional analysis at relatively low cost and provides the spectral range for the development of a comprehensive land cover and surface materials analysis and mapping.

Seaonality, nutrients availability and water stress alter the hyperspectral response of vegetation. This is true for both urban and nonurban applications. A large body of knowledge should be transferable from studies in nonurban vegetation to the urban landcover analysis, but further research is evident.

The 20 meter spatial resolution of AVIRIS is a relative limitation in its. use with IFSAR. Transitional land covers across the individual pixels complicates classification and delineation of building footprints. Although dependent on shape of the building, very large structures are affected less by this problem, since the ratio of perimeter pixel edges to interior pixels is less as the building size increases.

The use of spectral libraries for urban materials and land covers to perform subpixel analysis has the potential to diminish the limitation of the spatial resolution of AVIRIS data for urban analysis. Also other hyperspectral sensors are becoming available which have a finer spatial resolution. To establish that this integrative methodology is accurate and robust over differing urban landscapes, we need to apply it to a number of buildings in a variety of urban settings.

The integration of IFSAR and AVIRIS provides information regarding the vertical size and the spatial extent for the natural topography and human structures in an urban area. The 3-D measurements merged with the radar intensity and hyperspectral classification of the extended scene has the capability to provide a powerful information base. In addition, the extended image provides orthorectified positioning, relative locational and contextual information necessary for the creation of a more comprehensive geographic information systems approach.

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Literature Cited

Casciati, F., P. Gamba, F. Giorgi and Alessandro Mecocci, 1997. "Planning a RADATT Extension," GIS and Applications of Remote Sensing to Damage Management, "conference proceedings, Greenbelt, MD, Jan. 13-15.

Chavez, P. S., Jr., and Bowell, J., 1988. Comparison of the Spectral Information Content of Landsat Thematic Mapper and SPOT for Three Different Sites in the Phoenix, Arizona Region."

Photogrammetric Engineering and Remote Sensing, 56, 1699-1708.

Elachi, C. 1988. Spaceborne Radar Remote Sensing: Applications and Techniques, IEEE Press.

Goetz, A.F. et al. 1985. "Imaging Spectrometry for Earth Remote Sensing," *Science* **228:1147-1153.**

Gong, P., and P.J. Howarth, 1992. "Land-use Classification of SPOT HRV data using a Cover-Frequency Method," *Int. J. Remote Sensing*, Vol. 13, No. 8, 1459-1471.

Gouinaud, C., Tupin, F., and Maitre, H. 1996."Potential and Use of Radar Images for Characterization and Detection of Urban Areas," IGARSS-96, Firenze, volume 3, pages 2461-2463.

Haack, B, N. Bryant and S. Sdams. 1987. "An Assessment of Landsat MSS ant TM Data for Urban and Near-urban Landcover Digital Classification, *Remote Sensing of the Environment, 21*, pp. 201-213.

Houshmand, B., 1996. "A Geometrical Optics Model for Interferometric Synthetic Aperture Radar Height Measurements For Urban Areas, in URSI Proceedings, July 21.

International Geosphere-Biosphere Program. 1995 Land Use and Land Cover Change - Science Research Plan, IGBP Report No.35, edited by B. L. Turner et al. (IGBP, Stockholm).

Jensen, J. R., 1981, Urban Change Detection Mapping Using Landsat Digital Data. *The American Cartographer, 8, 127-147.*

Jensen, R. J., D. J. Cowen, J. Halls, S. Narumalani, N. Schmidt, B. A. Davis, and B. Burgess, 1994. "Improved Urban Infrastructure Mapping and Forecasting for BellSouth Using Remote Sensing and GIS

Technology," *Photogrammetric Engineering & Remote Sensing, Vol. 60,* No. *3,* pp. *339-346.*

Khorram, S., Brockhaus, J. A., and Cheshire, H. M., 1987. Comparison of Landsat MSS and TM data for Urban Land-use Classification. *I. E.E.E. Transactions on Geoscience and Remote Sensing.* Vol. GE-*25,* No. *2,* pp. *238-243.*

Madsen, S. N., H.A. Zebker, and J. Martin, 1993. "Topographic Mapping Using Radar Interferometry: processing Techniques, *IEEE Trans. Geosci. Remote Sensing,* vol **31, No. 1.**

Ridd, M.K. 1995. "Exploring the VIS Model for Urban Ecosystems Analysis through Remote Sensing." *Inter.J. of Remote Sensing,* Vol. 16, no.12, pp2165-2186.

Rodriguez, E., T.R. Michel, J.M. Martin and B. Houshmand, "Automated Map Generation Using C-band IFSAR Data," *IEEE Trans. Geosci. Remote Sensing,* submitted 1996.

Smith, M.O. et al. 1990. " Vegetation in Deserts: A Regional Measure of Abundance from Multispectral Images." *Remote Sensing of the Environment,* 31:1-26.

Soumekh, M., 1995. "Reconnaissance with Ultra Wideband UHF Synthetic Aperture Radar," *IEEE Signal Processing Magazine*, pp. 21-40, (July) .

Webber,C., and J. Hirsch, 1992. " Some Urban Measurements from SPOT Data: Urban Life Quality Indices, " *Int. J. Remote Sensing,* Vol. 13, No. 17, 3251-3261.

Weydhahl, W., X. Becquey, and T. Tollefsen, 1995. "Combining ERS-1 SAR with Optical Satellite Data over Urban Areas," IGARSS-95, Firenze, volume 3, pages 2461-2463.

List of Figures

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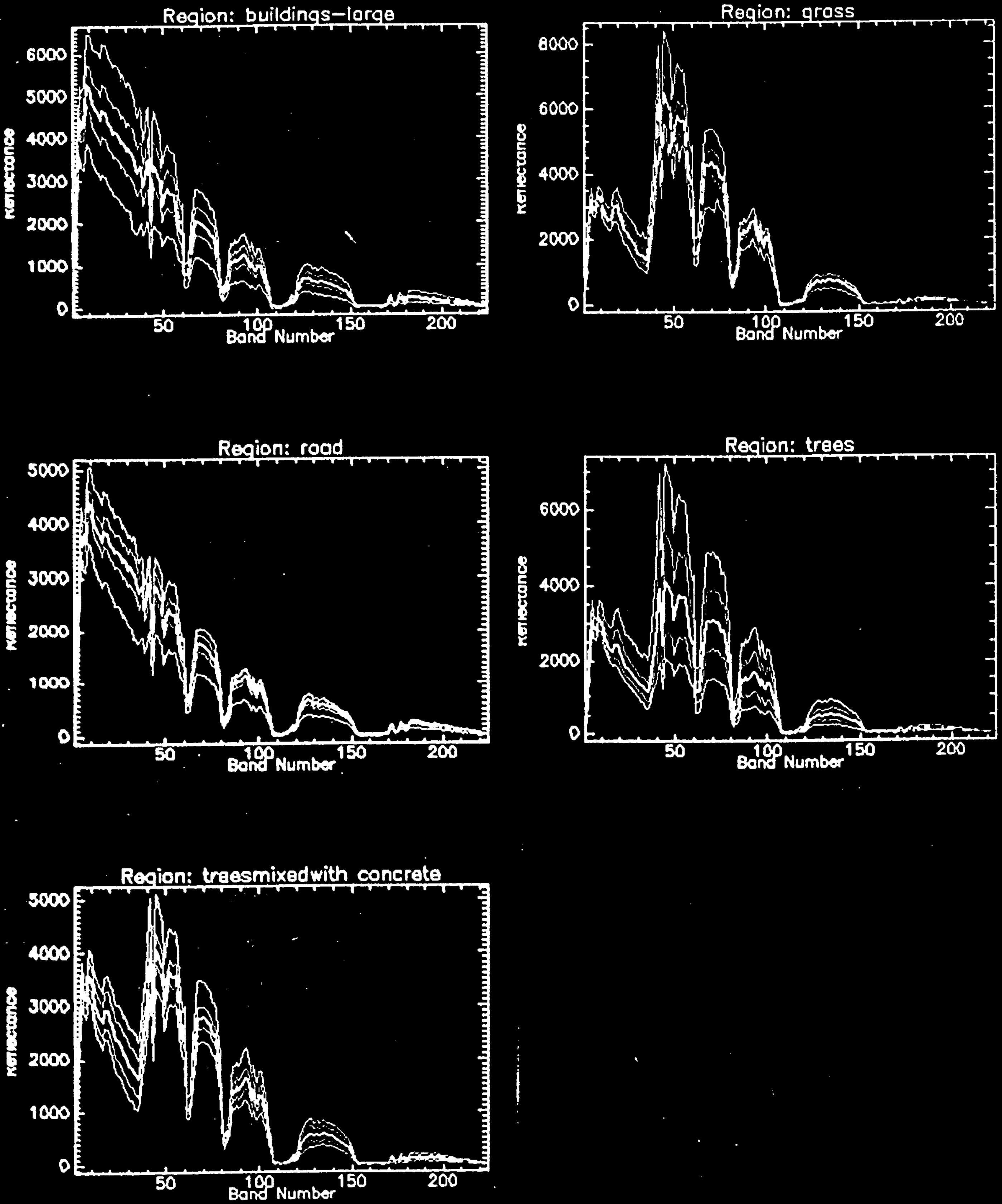

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Band Number
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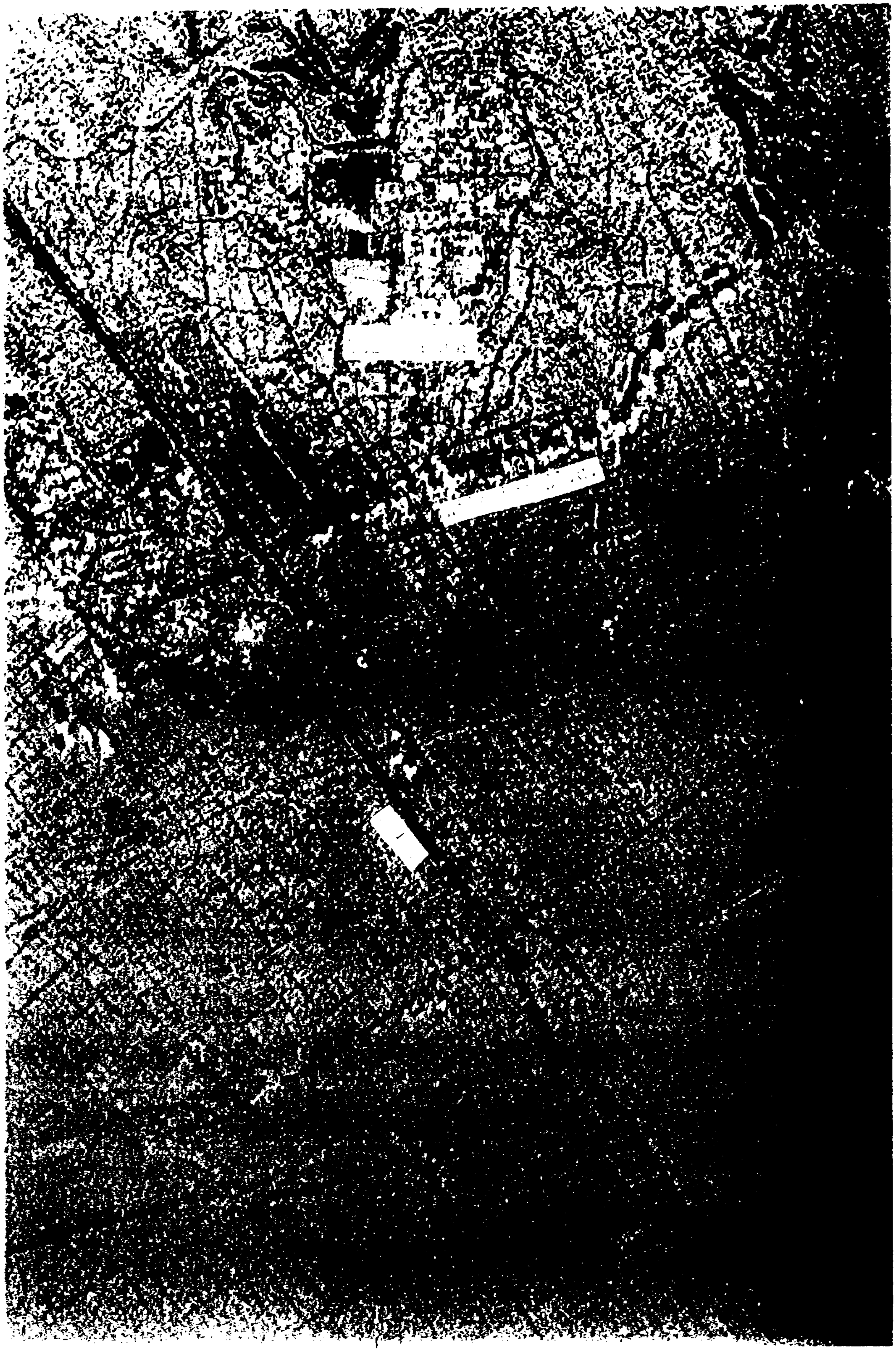

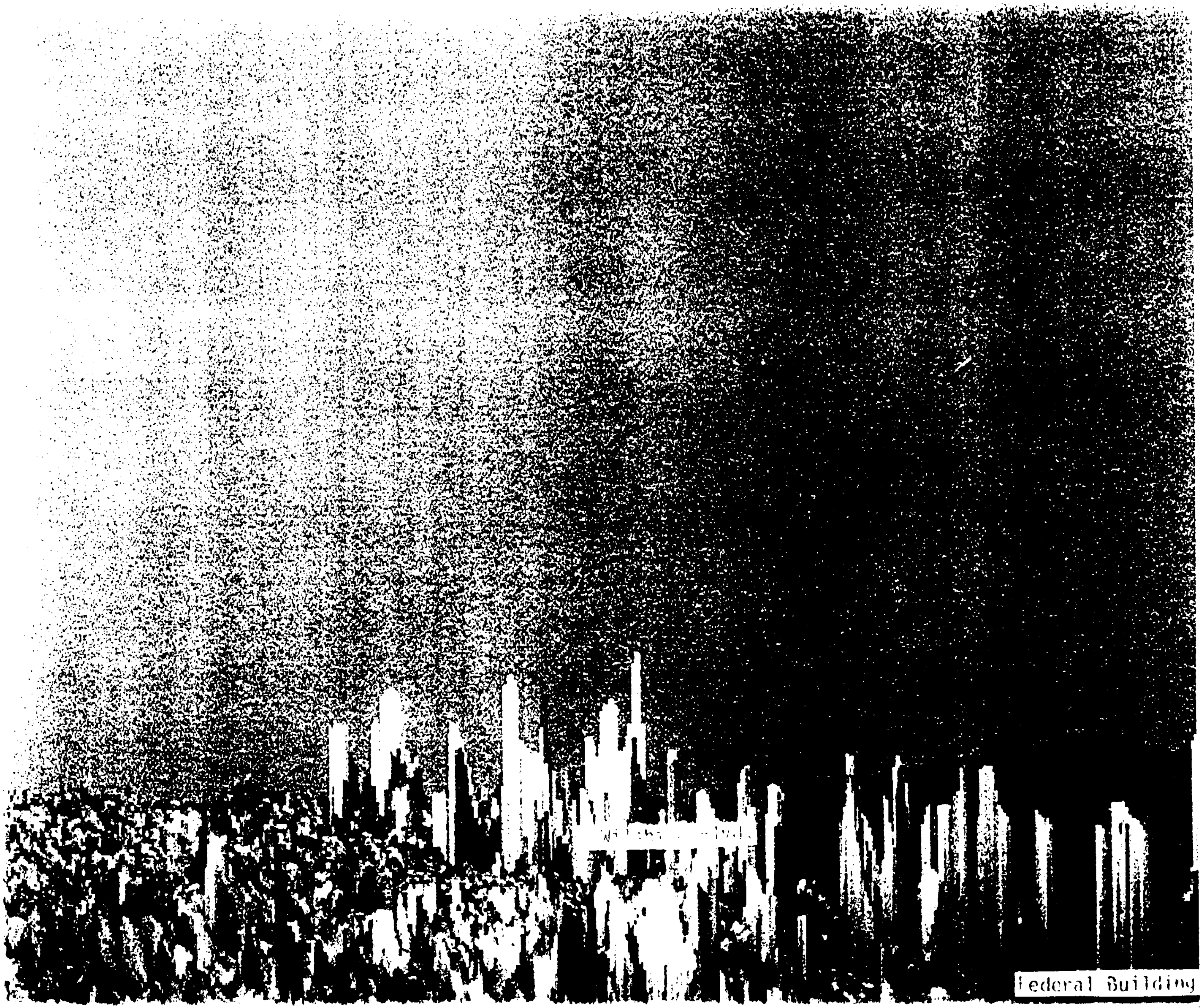
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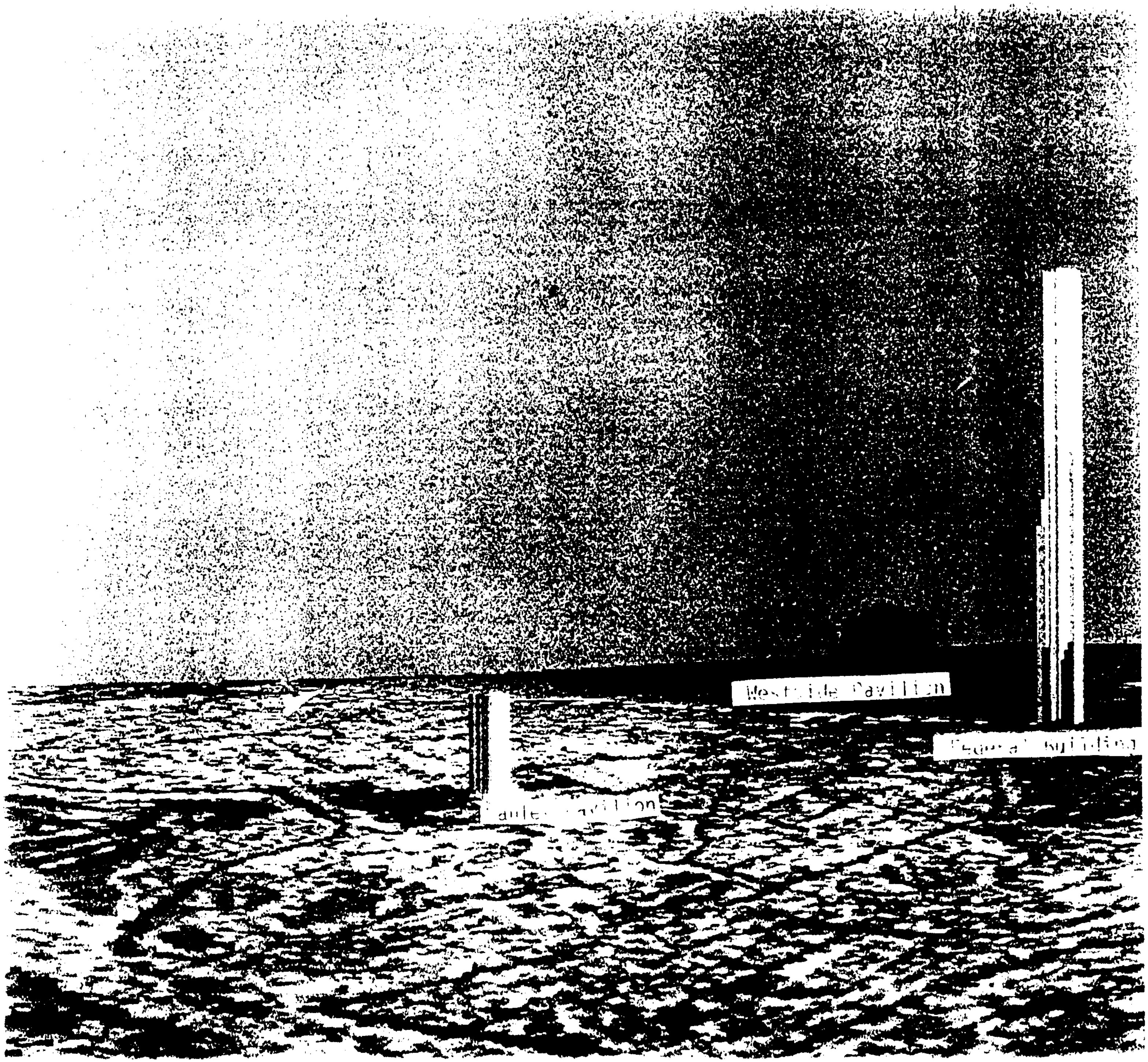
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